Computer Science 703
Advance Computer Architecture

2008 Semester 1

Lecture Notes
5Mar08
Moore's Law

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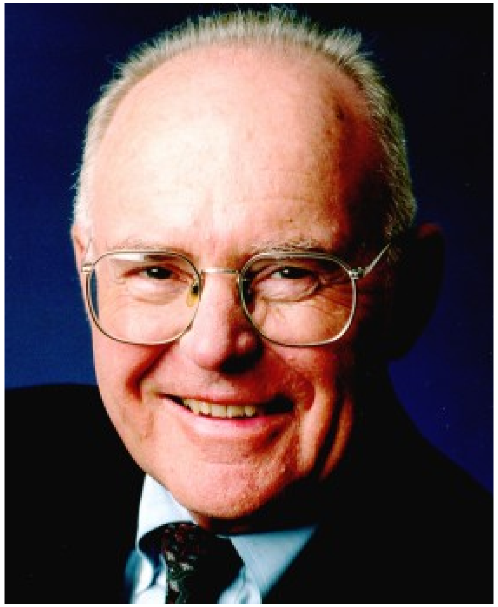
Assignment for Tomorrow

- What previous courses have you taken that prepared you for this paper? (Computer organization, operating systems, database, etc.)
- What are you hoping to get out of this paper? (Knowledge about advance architecture? Transactional memory? Other)
- Would you prefer that the assessment be adjusted to increase the weight of a project?
  - Currently 60% exam, 25% assignments/project, 10% test, 5% class participation
  - Adjust to 50% exam, 40% assignments/project, 10% test
  - Other (suggestions welcome)
- Bring to class or E-mail before class
  - Not taking class for credit? This assignment is optional!

Dr. Gordon Moore

1965



2003

Moore’s Data: 1965

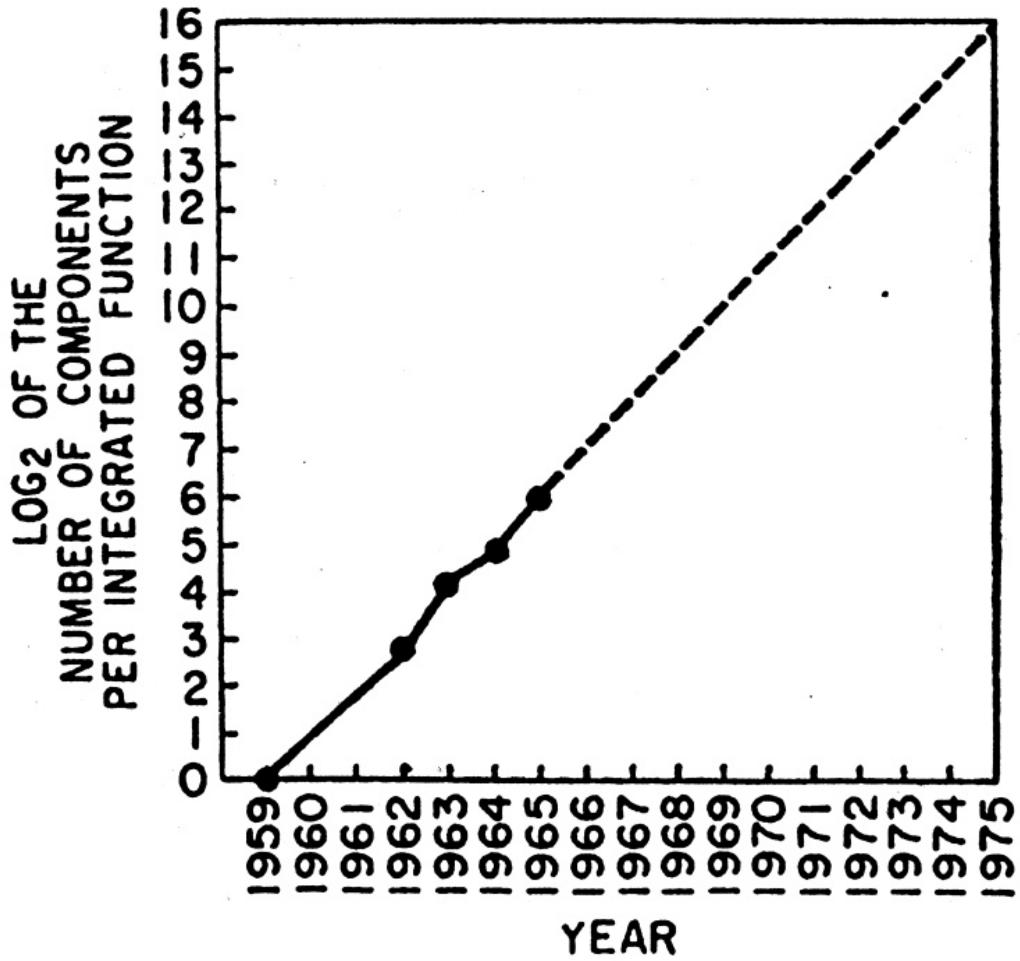


Fig. 3.

Moore's Observation

"The complexity for minimum component costs has increased at a rate of roughly a factor of two per year.... *Certainly over the short term* this rate can be expected to continue, if not to increase. *Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least ten years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65 000.*"

— Gordon E. Moore
"Cramming more components onto integrated circuits," *Electronics*, pp. 114-117, Apr. 1965.

Moore’s Prediction

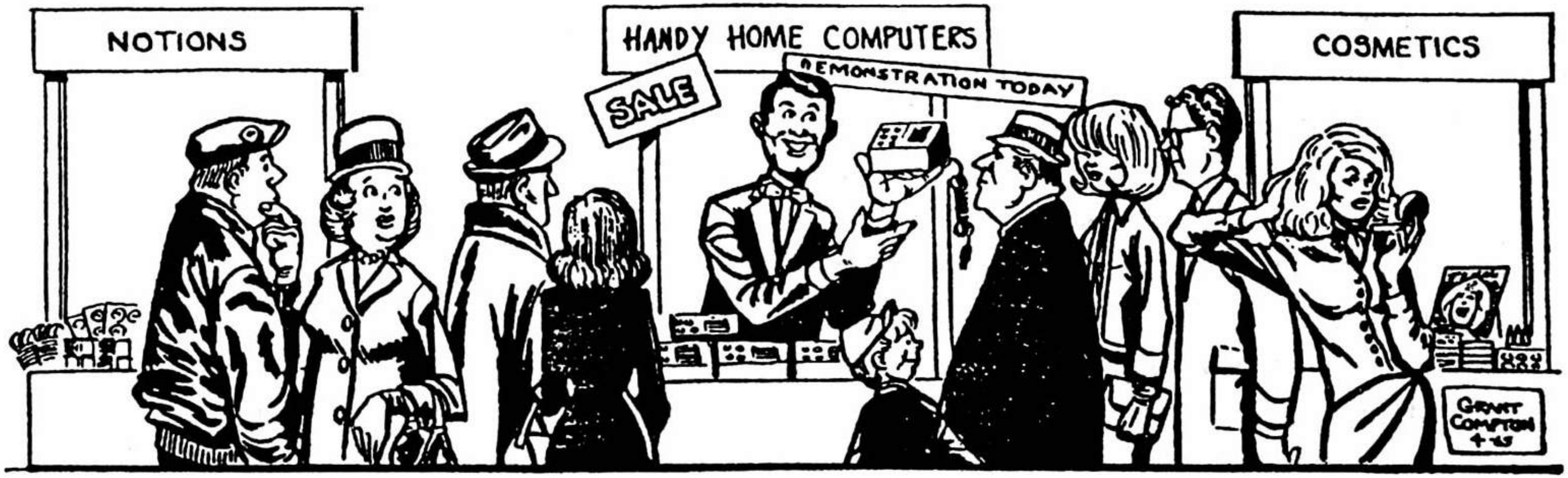
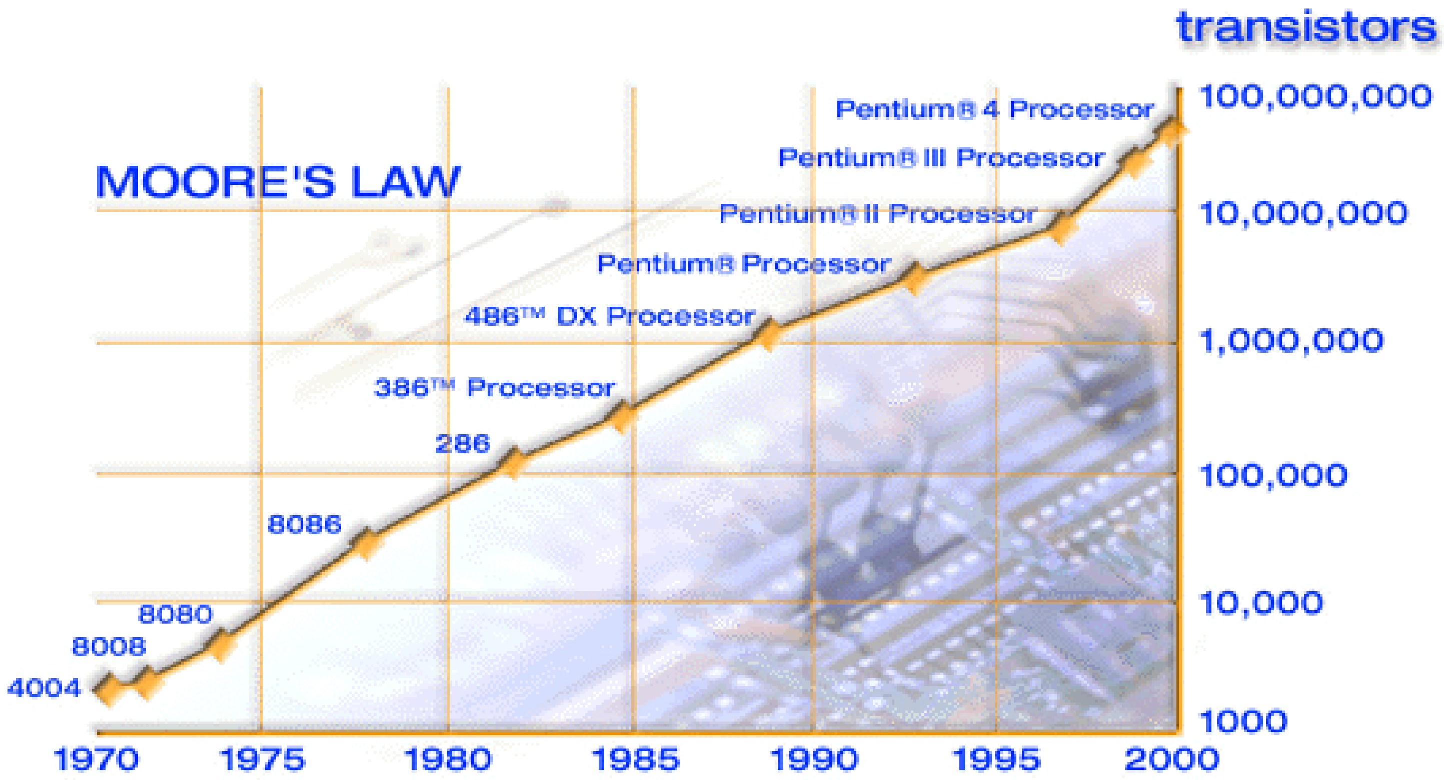


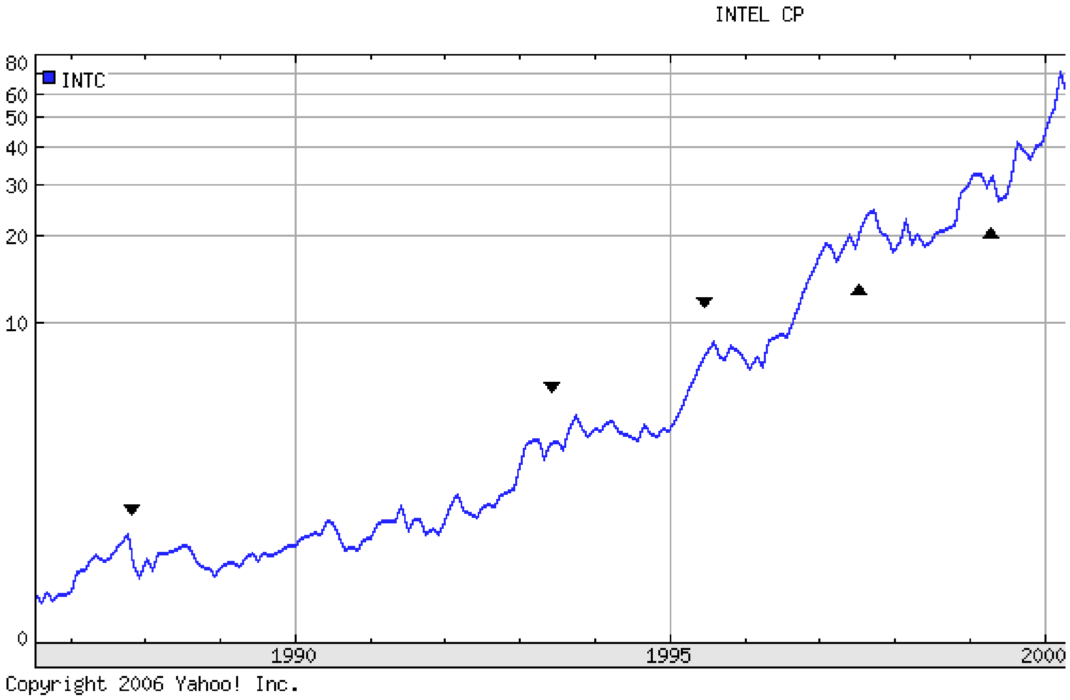
Fig. 2.

Moore's Company



http://www.intel.com/research/silicon/mooreslaw.htm

Moore's Motivation



Moore's Formula

Minimum cost # of components/chip

$$N = 2^{(year - 1959)}$$

Extrapolating to 2008,

$$N = 2^{(2008 - 1959)} = 564 * 10^{12}$$

= *564 Trillion transistors*

Moore's Correction: 1975

There is no room left to squeeze anything out by being clever. Going forward from here we have to depend on the two size factors – bigger dice and finer dimensions.

— Gordon E. Moore
Electronic Devices Meeting, 1975.

Moore's Corrected Formula

Minimum cost # of components

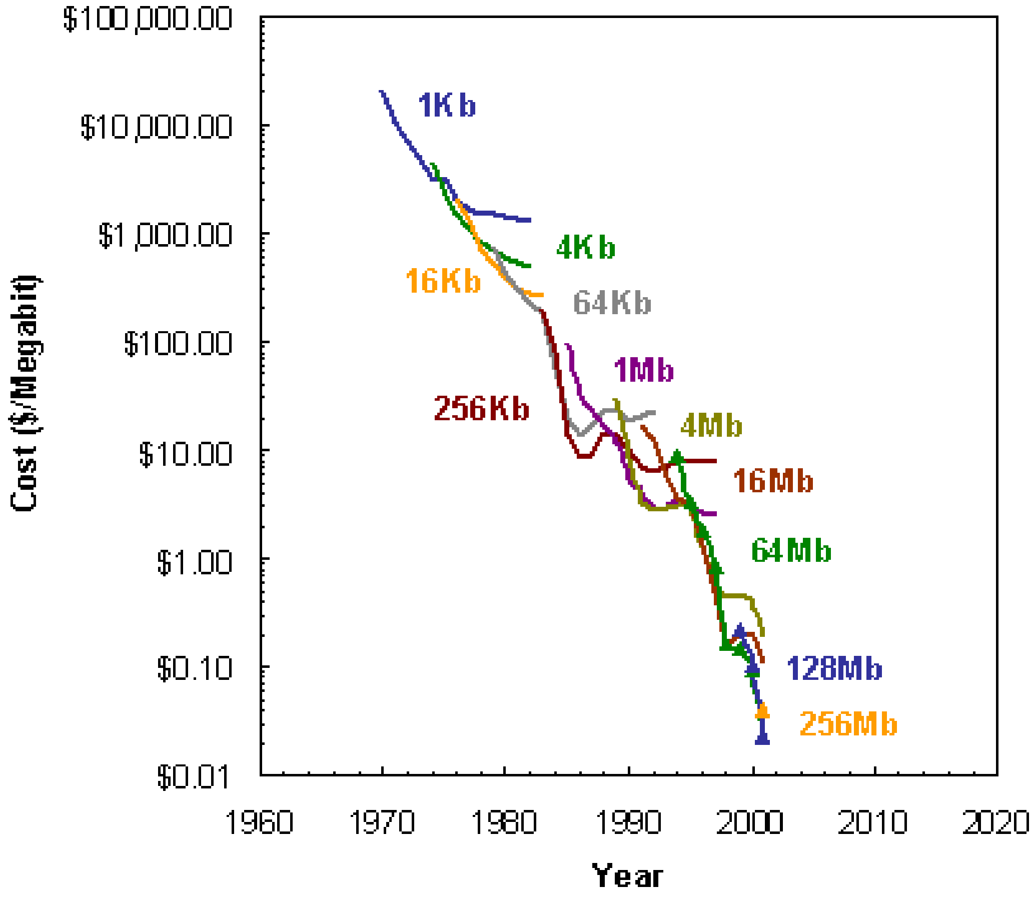
$$N = 2^{(year - 1959)/1.5} = 1.59^{(year - 1959)}$$

Extrapolating to 2006,

$$N = 1.59^{(2008 - 1959)} = 6.8 * 10^{9}$$

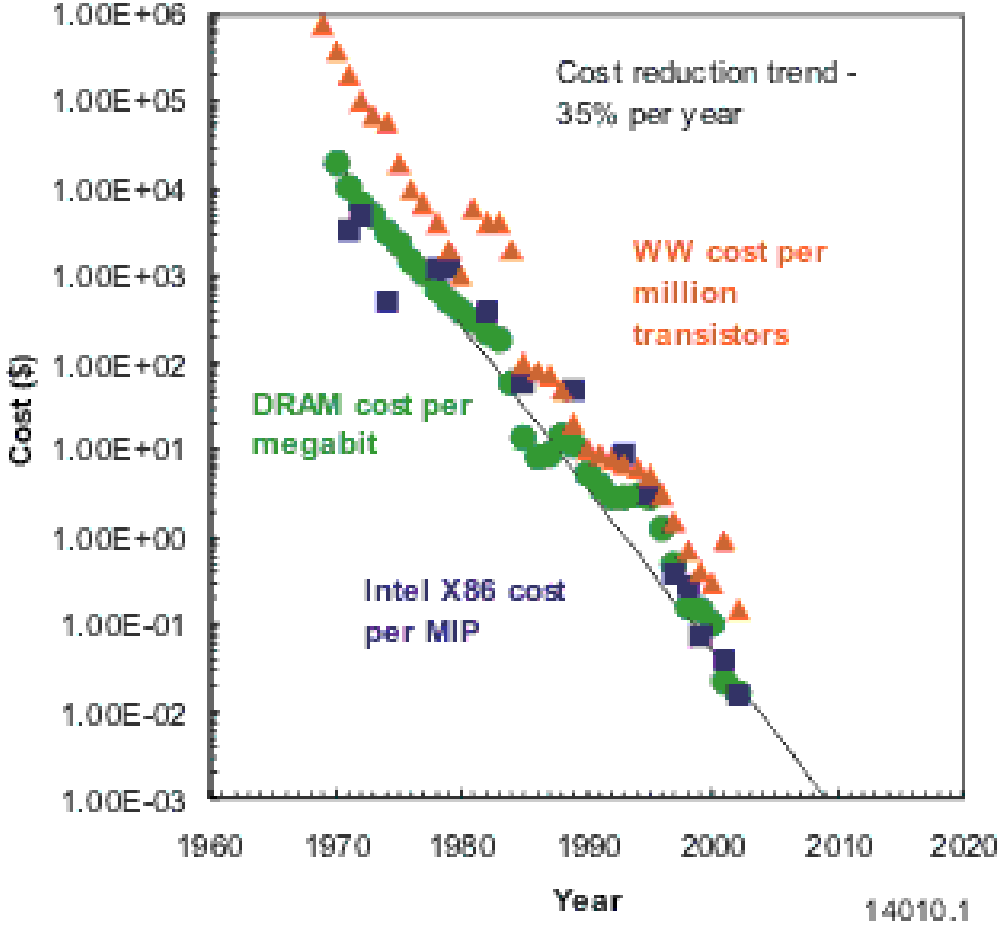
= *6.8 billion transistors*

Drop in DRAM Cost per Bit



http://www.icknowledge.com/economics/dramcosts.html
IC Knowledge, 2001

Other Measures of Cost Reduction



http://www.icknowledge.com/economics/productscostscosts2.html
IC Knowledge, 2001

Total Transistor Production

- Reduction in cost: 35%/year
- Increase in sales volume: 15%/year
- Increase in transistor production:

$$1.15/.65 = 77\%/\text{year}$$

My estimate for 2008: ~1,900,000,000,000,000,000,000

i.e., 1.9 sextillion transistors!

Transistors ≠ Performance

- Limited gain in performance derives directly from semiconductor gains

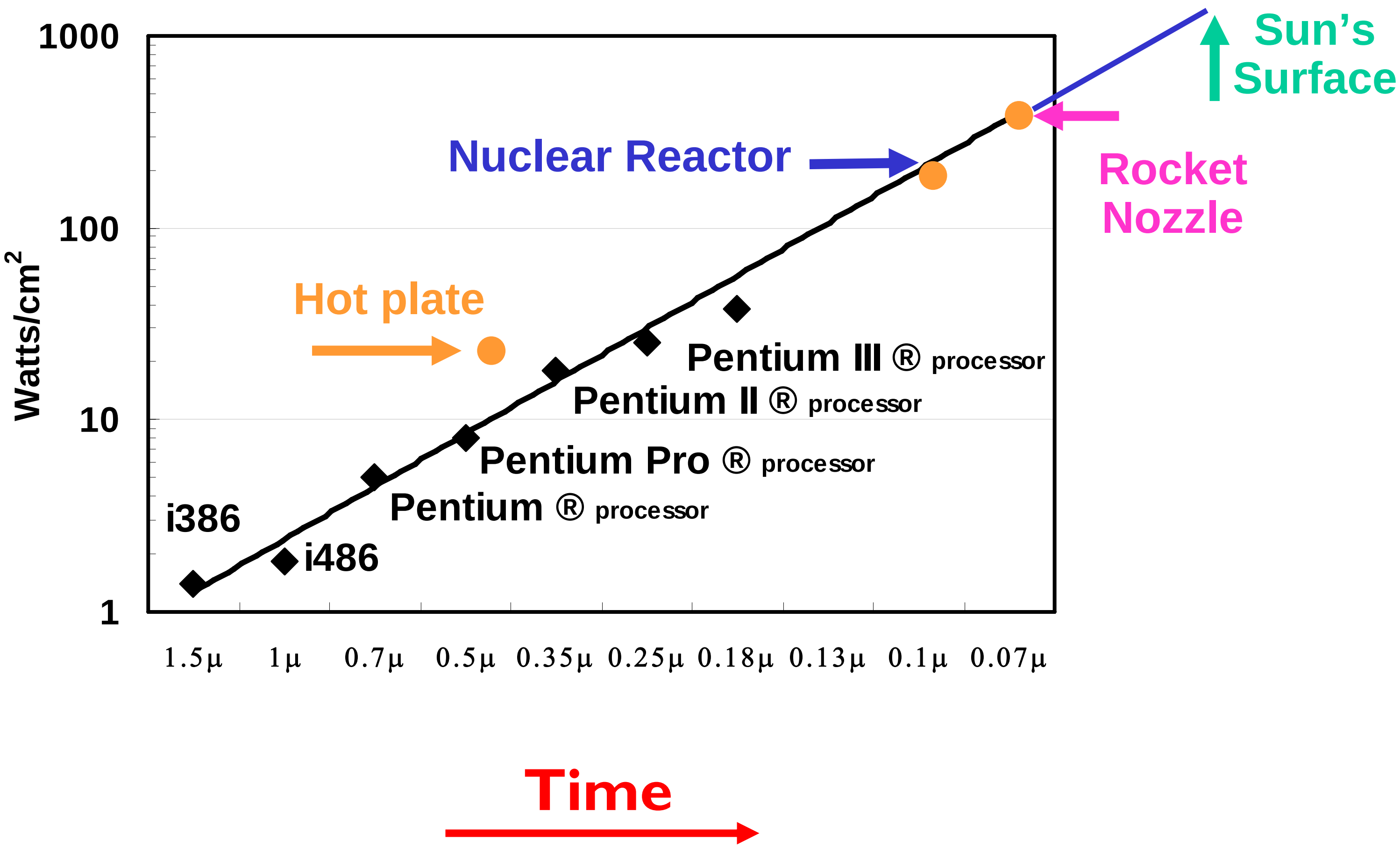
- The rest comes from better architecture

Performance Gains from Physics

Smaller transistors are closer together

- switch faster
- communicate faster
- require less energy

A Different Exponential Law



Fred Pollack, Intel Corp. 2000

Joy's Law

"PERFORMANCE of a microprocessors doubles every three years."

—William Joy, 1980

Also known as "Popular Moore's Law"

Joy's Law

Relative Performance of Microprocessor

$$P = 2^{(\text{year} - 1980)/3} = 1.26^{(\text{year} - 1980)}$$

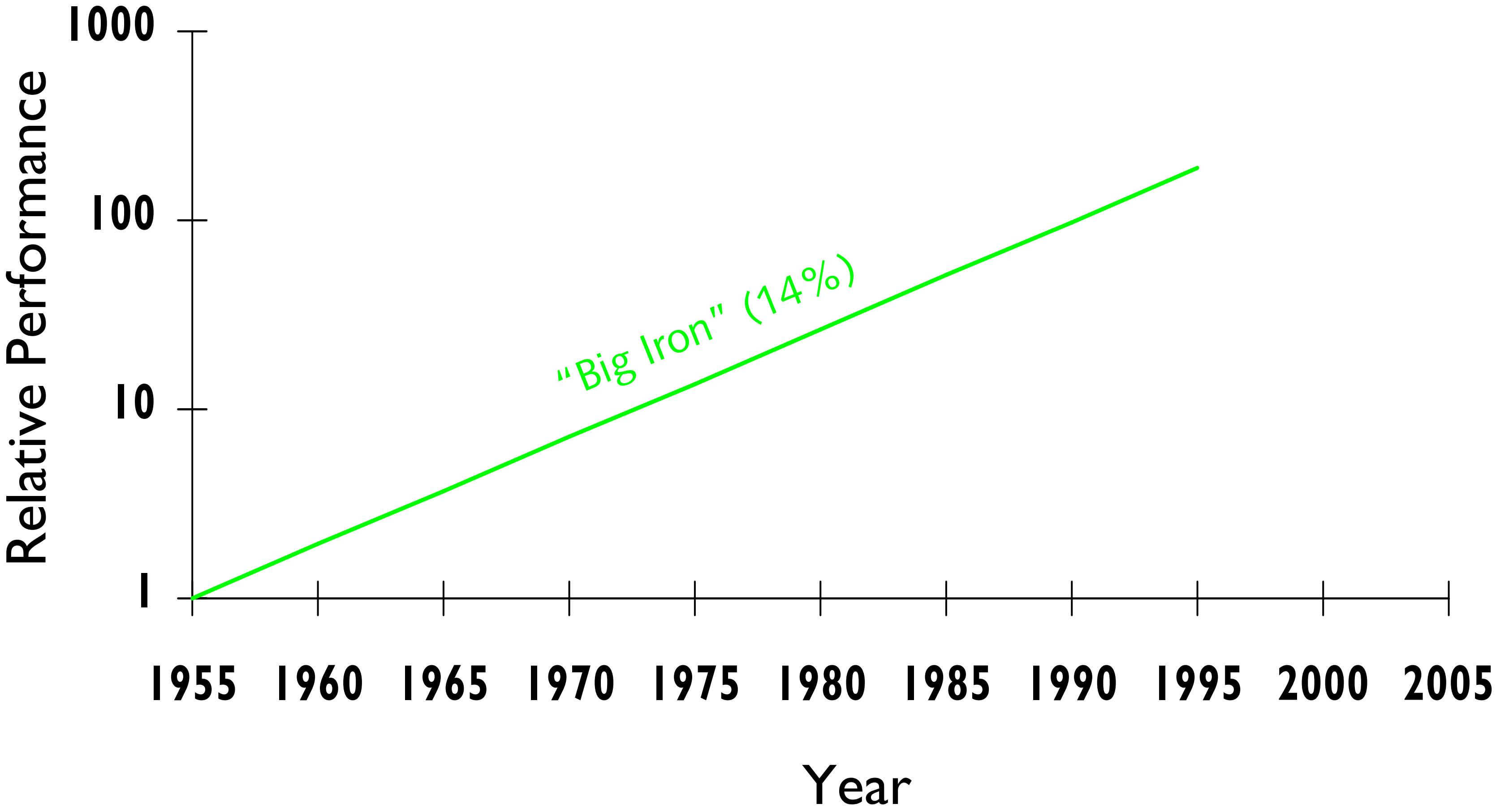
Extrapolating to 2008 relative to 1980,

$$P = 1.26^{(2008 - 1980)} = 645X$$

Realistic rate to **2006** was closer to 40%/year:

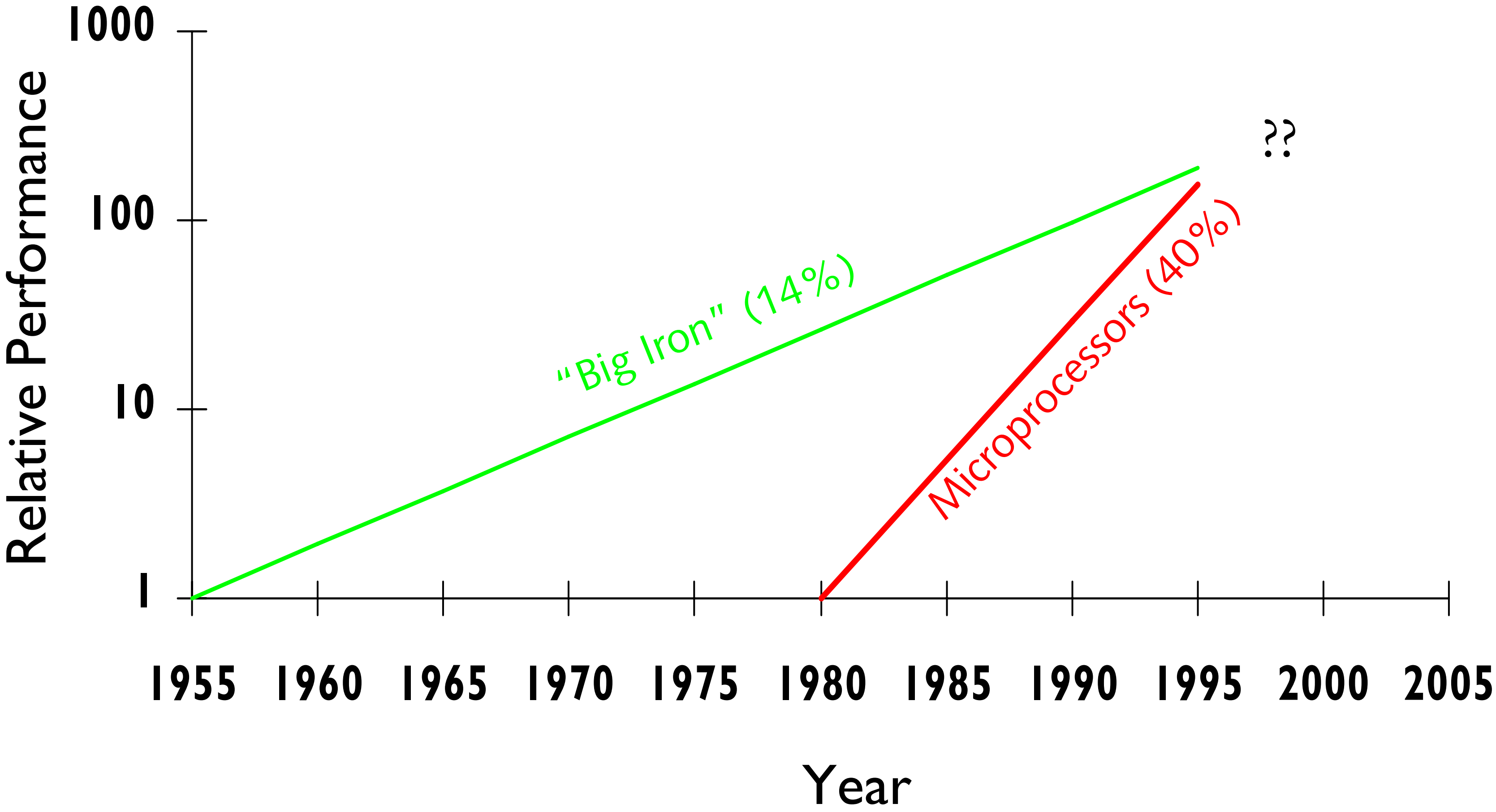
$$P = 1.40^{(2006 - 1980)} = 6300X$$

Best Uniprocessor Performance 1955-1995



2008
YEAR
PRESENTATION
The University of Auckland | New Zealand

Best Uniprocessor Performance 1955-1995



2008

YEAR

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News [Processors]

Friday 15th October 2004

Intel abandons clock speed chase and drops 4GHz Pentium 9:31AM

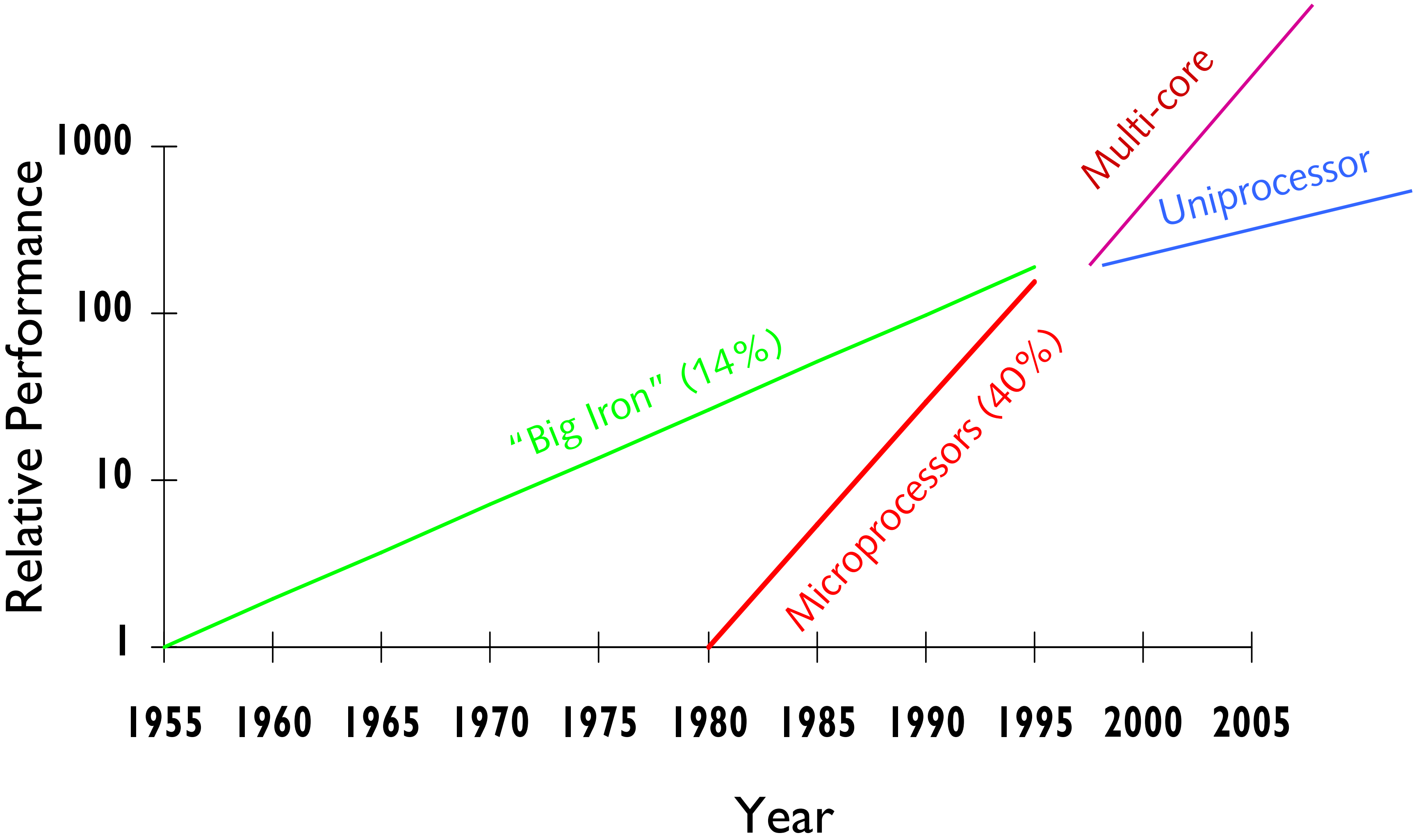
In another embarrassing admission in a year scattered with them, Intel has announced that it is to cease development of the 4GHz Pentium processor. For now the 3.8GHz part will remain the highest clock speed. Instead, the company says that it will be transferring its engineers to work on the dual core designs demonstrated at the recent Developer's Forum.

The unexpected announcement marks the end of an era for Intel. Ever since the launch of the 4.77MHz 8088 around which the original IBM PC was designed, the company has largely depended on ever increasing clock speeds to boost performance. However, recently Intel and arch-rival AMD have been having greater problems in producing reliable parts that could cope with the amount of heat generated by these clock speeds.

First AMD and now Intel have changed tack away from raw clock speed towards

Source: http://www.comp-buyer.co.uk/buyer/processors/news/64478/intel-abandons-clock-speed-chase-and-drops-4ghz-pentium.html

Multi-cores!


Relative Performance
1000
100
10
1
"Big Iron" (14%)
Microprocessors (40%)
Multi-core
Uniprocessor
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

Microprocessor Improvements

- Microprocessors are a good match for Moore's Law: single-chip processors
- Previous technology created a "bag of tricks" to be exploited

Architectural Advances 1950-1990

• Branch prediction:	1995	(1959)
• Out-of-order issue:	1993	(1963)
• Multi-threading:	1995	(1963)
• Cache memories:	1985	(1965)
• Superscalar Processing (mult instrs/cycle):	~1990	(1960s)
• Register renaming:	~1992	(1967)
• Deep pipelining:	~1993	(1976)
• Speculative execution:	~1995	(1983)

When Does It End?

"We're half way down the learning curve [after 11 years]"

— Professor Carlo Sequin, UC-Berkeley, 1976.

"It can't go on much longer. We're pushing against some really fundamental limits!"

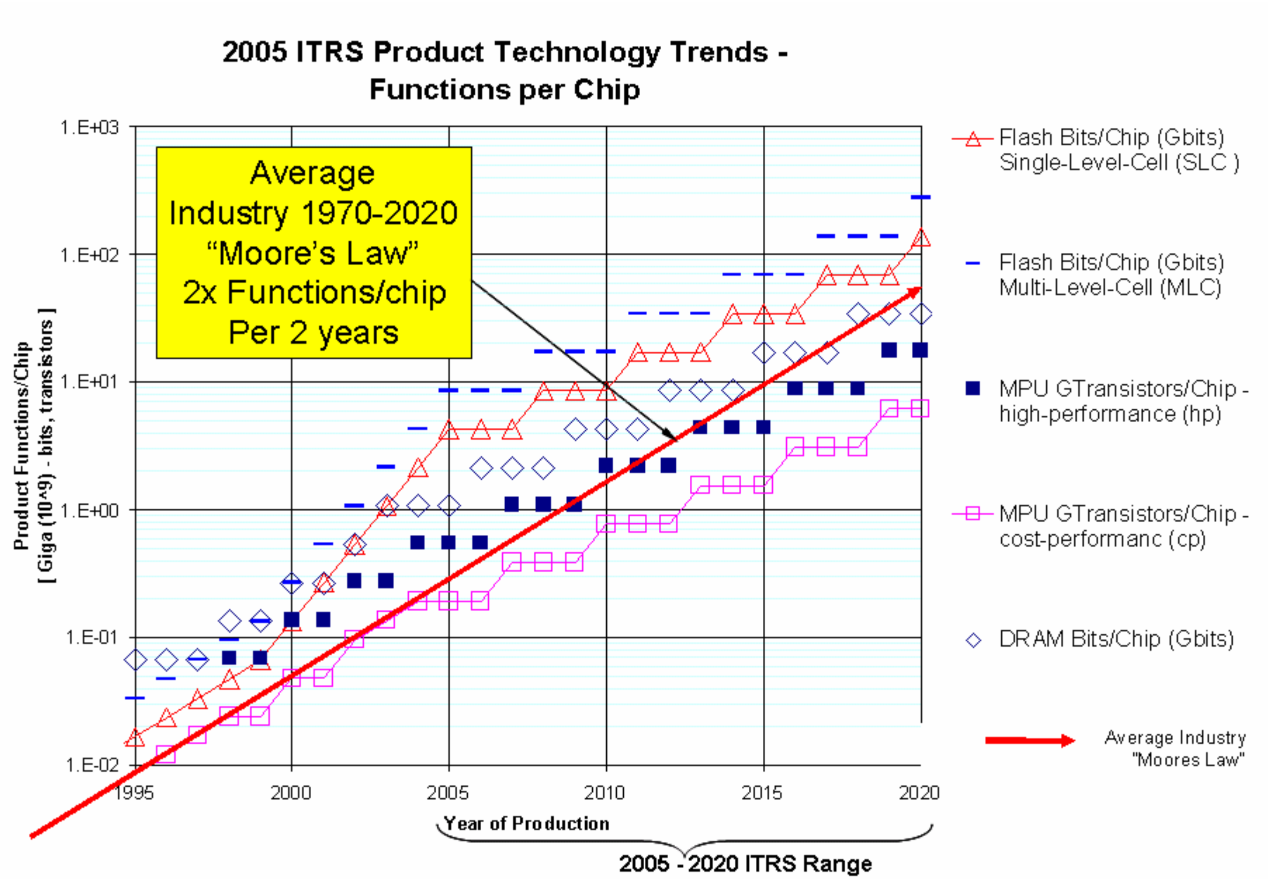
— Dr. Joel Emer, DEC, 1996.

The End is Not in Sight

The Roadmap continues to call for reduction [until 2012] in geometric dimensions in accordance with Moore's Law, but allows for short-term adjustments based on current practices.

— Semiconductor Industry Association: The (US) National Technology Roadmap for Semiconductors, 1997.

The End is Not in Sight



International Technology Roadmap for Semiconductors, 2005 Edition (Executive Summary). Figure 10, p. 68.

Or is it?

The continued research and development efforts in our industry have brought about reacceleration and diversification of scaling, although the 2003 edition of ITRS reported on the deceleration of scaling envisaged by Moore's Law to a three-year cycle. Flash devices' scaling is still a two-year cycle until 2006, MPU is a 2.5-year cycle until 2010, and DRAM is a three-year cycle. The word "node" cannot define [a] technology trend clearly anymore. In the chapter on PIDS, it is observed that there are many choices to improve MOSFET performance, which we call "Parallel Paths" of planer bulk MOSFET, FD-SOI MOSFET, and Fin-FET. The ITRS is entering a new era as the industry begins to address the theoretical limits of CMOS scaling. There remain many technological challenges to be overcome to achieve continuing growth of the semiconductor industry.

International Technology Roadmap for Semiconductors, 2005 Edition (Executive Summary), p. 11.